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THE RESEARCH COUPLET: RESEARCH IN PURE SCIENCE AND INDUSTRIAL RESEARCH

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PURE research, the morning dream of the scientist, has been referred to as the region of the scientific sublime; for, high and clear above all the necessary but prosaic activities of technology, far removed from the pettier aims of mere financial betterment, investigational accomplishment in pure science may be said to point one way to a goal of academic loftiness. Indeed, in the past, those devoted to pure research encouraged the impression that pure science, "a sort of preserve for intellectual sportsmen," was esoteric and distinctly apart from the ordinary affairs of life, and made no effort to disclaim the implication that pure scientists necessarily brought to their inquiries a higher and subtler intellect than those who were engaged in applying science to the needs of the community.

This adopted aloofness and lack of sympathy with respect to municipal and industrial practise have undoubtedly been prominent in retarding the solution of a number of the great problems of both chemical and mechanical technology, and have, moreover, acted as a barrier to needed cooperative effort.

It is certain, however, that, with the recent elaborate development of industrial research and the general recognition of the high quality of work which it demands, this view of the relation of pure and applied science has now entirely disappeared. In fact, while pure science ever has been, and ever must be, the safeguard of industrial research—the wellspring of experience and wisdom—it is generally conceded that the industrial investigator always will be the translator of the language of pure science to the manufacturing world, and in many cases, where necessity arises, the originator as well as the applicator of scientific method. Both pure and applied research are of the same order of importance, and each has its own related field.

Industrial research has for its immediate province the scientific extension of manufacturing. It should be borne in mind, however, that a discovery made in pure science to-day may find

application in manufacturing operations to-morrow, and that such industrial application, though its precise form can not always be foreseen at the time, has come to be an expected incident in the after-life of the discovery. The wide view is now taken that, in considering the needs of industry, pure-science investigation has as essential a contributory function as that specifically devoted to the attainment of some technologic objective. Such pure researches may provide raw material for industrial research, and, owing to the interdependence of modern scientific investigations, progress in one subject may have a marked bearing on development in others. There is thus provided a distinct industrial stimulus for research in pure science. To illustrate, the investigational activity in physics in the pure field has been incited by the development of electrical and mechanical engineering; the departments of physics in our universities are unquestionably more productive because of the stimulating influence of the accomplishments of the engineering profession. Mathematics and astronomy have not had this direct encouragement from industry, but geology and botany have been immensely benefited by the researches indicated as desirable by technical chemistry.

The principal differences between those investigations which are undertaken for the purpose of furnishing material for industrial development and those conducted by scientists with the object in view of widening the boundaries of human knowledge are as follows:

1. Industrial research utilizes economically the unapprehended inspirations of the pure scientist; for applied science reasons retrospectively, employing the observations of pure science. Because of this fruitful dependency, pure-science research is nurtured by industry in its own well-directed laboratories as well as in those of our universities.

2. Industrial research is, therefore, likely to be more spontaneous and to depend more upon the initiative of the workers in its field.

The fundamental differences between pure research and industrial research are, indeed, traceable to the differences in the poise and personality of the representatives of each type of scientific investigation. Success in genuine industrial research presupposes all the qualities which are applicable to success in pure science, and, *in addition*, other qualities, masculine and personal, more or less unessential in the pure research laboratory. The late Robert Kennedy Duncan appropriately suggested that the difference between industrial chemistry and

pure chemistry might be compared to the difference between poetry and prose, in the sense that in order to write good poetry it is essential to possess all the qualities of the prose writer, together with others superimposed upon them.

3. As the result of these recognitions, industrial research is rapidly becoming definitely organized to cover certain fields in the domain of science.

Applied science, the essence of industrial research, has been alluded to as bilateral in that its inquiries, conducted in the service of public welfare, may, when it is found to be necessary through a dearth of required information, eventuate in the discovery of scientific data as well as furnish and interpret the findings of the pure scientist; but, invariably, the original scientific work of the industrial investigator results from the realization of the requirement for a sojourn in the field of pure science. There are not, therefore, two sides to applied science, but two divisions of science which are difficult to define with constant accuracy because of their proximity. The needs of industry are so varied and so numerous that its research men are frequently crossing the flexible border to pure science, but time is the main factor in all industrial investigations and these visits are as brief as they are repeated.

RESEARCH IN CHEMISTRY

These facts are clearly indicated in the history of chemistry, "the eldest sister of all sciences and parent of modern industry."

The great triumphs of pure chemistry are philosophic achievements—the product of an antecedent experience in physical investigation of the widest and most searching character; and all of the conspicuous accomplishments in the domain of chemical industry—in fact, its actual growth and development—are the outcome of the application of these and other channels of knowledge explored by the investigators in pure chemistry. Indeed, we must welcome as one of the most fortunate advances in the direction of a solution of the important problems of chemical technology the fact that of recent years there is a growing tendency to recognize the two paths which alone lead thereto—experience and research. The recognition of the national essentiality of chemistry has thus profoundly modified the once combatant situation respecting pure and industrial research; while both groups of investigators, regarding the idealistic counsel of Schiller,

Does strife divide your efforts—no union bless your toil?
Will truth e'er be delivered if ye your forces rend?

have pressed onward, in their different paths, they have found a common aspiration, the development of social and industrial economy, and therefore constantly draw nearer to a knowledge of highest efficiency in mutual covenant.

CLASSIFICATION OF RESEARCH IN PURE CHEMISTRY

Research in pure chemistry is to-day conducted in three distinct fields; these classes follow:

1. Investigation after facts or principles of theoretical interest or importance, and which have decidedly no direct bearing on or relation to present-day chemical technology.
2. Research conducted from a similar viewpoint, usually academic, and for the same purpose—namely, to add to the knowledge of pure chemistry—but which is also of technical interest. Original work of this type has, in fact, constituted the basis of many successful techno-chemical processes.
3. Scientific inquiry of largely or entirely a theoretical nature, resulting from or as a by-path of industrial research: research of this nature may only be classed as pure, but not infrequently it directly enriches technology. Investigatory work thus classified has indeed been active in elevating industrial chemistry by continuously infusing scientific spirit therein.

It is clear that the last two classes are closely related to the purposeful study of manufacturing problems; for research of the second type contributes to industrial progress by its suggestive import, while the third class may be of no greater significance, notwithstanding the fact that it is the outcome of planned industrial research; the one is a helpful adjuvant to, the other a by-product of, techno-chemical investigation.

CLASSIFICATION OF RESEARCH IN APPLIED CHEMISTRY

Investigatory work in applied chemistry now mainly pertains to the intensive study of three types of problems, namely:

1. *The Preparation of Chemical Products.*—The techno-chemical research of this class is either synthetic or engineering. It is in synthetic chemistry that pure chemical science receives the most due in industry, particularly because of the synthetic production of pharmaceutical substances. Many of the noteworthy accomplishments in this field have been effected in laboratories of factories. The chemical engineering

division of this class of investigation relates to the improvement of existing processes and to the discovery of new procedures of manufacture.

2. *Research Having for Its Object the Ascertainment of Uses of Manufactured Products.*—In the pharmaceutical products industry, research of this type is conducted in intimate co-operation with pharmacology, chemo-therapeutics, bacteriology, and commercial science. In the heavy chemical industry, the line of inquiry is, of course, almost entirely chemo-economic in nature.

3. *The Elaboration and Perfection of Analytical Methods,* the indispensable aids in the control of manufacturing operations.

THE DEVELOPMENT OF INDUSTRIAL RESEARCH

Stupendous developments in industrial research have taken place during the past decade, particularly as the result of the realization by manufacturers of the functions of applied chemistry. Manufacturers who have been benefited by the application of science to industry have not been content to await chance discoveries, but have established well-equipped laboratories and strong research staffs. Further incentives in this direction have been provided by the industrial progress achieved in Europe by similar means and by the influx of many scientifically trained men, principally from Germany. Then, too, a tendency toward national economy and a fear of the depletion of certain natural resources have directed attention to the importance of the scientific conservation of these unreplaceable assets. Moreover, some large industrial corporations have found it expedient to keep before the public the fact that investigations on a large scale ultimately bring considerable benefit to the community generally; that every scientific discovery applied in industry reacts to the public gain; and that consequently great industrial organizations are justified, since it is only where there are large aggregations of capital that the most extensive and productive research facilities can be obtained. There are a large number of manufacturing corporations and associations of manufacturers whose annual expenditures on research range from \$50,000 to \$500,000, and the tendency for each important industrial firm is towards the establishing of its own research laboratory. Certain of our research laboratory forces have been increased from 250 to 400 per cent. in the last ten years, and, since August, 1914, the staffs of a number of the largest laboratories have been enlarged from 25 to 100 per cent.

The research work thus commenced by corporations appears to develop through certain more or less well-defined stages, according to the character of the industry.¹ These stages may be presented as follows :

1. *Research Applied to the Elimination of Difficulties in Manufacturing*

In every industrial organization difficulties regarding materials and processes employed inevitably arise, tending to prevent smooth working and desirable economy. To overcome these troubles, investigation is necessary, which, if well planned and conducted thoroughly, locates the exact cause of the difficulty and eventually leads to its elimination. Some manufacturers may be content in such cases to apply rule-of-thumb methods, which, while occasionally effecting a temporary alleviation, do not preclude a fresh outbreak of similar trouble in the same or some other form. Progressive firms do not, however, resort to empiricism, but provide organized means for investigating and eliminating manufacturing difficulties, and the extent to which it is necessary to apply science to this end depends upon the nature of the product and the complexity of the manufacturing processes involved. In the largest manufacturing firms of every industry there is now usually ample scope for a scientific staff and laboratory facilities to deal with techno-chemical troubles. At least six American organizations have sixty or more research chemists engaged in this field of industrial research.

2. *Research Having Some New and Specific Commercial Object*

This variety of industrial research involves an intelligent appreciation of the trend of development of manufacture and the possible applications of a product, and a close study of the scientific features and new discoveries that will pave the way for its successful manufacture. Frequently the appreciation of the need in industry, for some new tool, method, or material, stimulates a deliberate search for means to satisfy that demand. Or, again, the development of manufacturing methods for producing commodities heretofore brought to a high state of perfection in some other locality or country may involve the development of appliances and processes of which no previous experience has been obtained.

¹ On the development of research, see Fleming's "Industrial Research in the United States of America," a report to the Department of Science and Industrial Research, London, 1917.

Many captains of industry have been sufficiently far-sighted to provide extensively for research of this character, and such facilities have been turned to very profitable account in connection with new industries developed since the outbreak of the World War. In many cases these laboratories not only supply the works with new inventions and discoveries, but are used to carry on the manufacture of products with which the works themselves are not well suited to deal. In fact, the research laboratories of a number of corporations pay their own way out of the profits arising from the sale of commodities thus produced.

3. Researches in Pure Science with no Specific Commercial Application in View

Among the most progressive firms there is a growing appreciation of the fact that almost every discovery in science ultimately may have influence on industry. The General Electric Company, the Eastman Kodak Company, and other American organizations devote increasing attention to research of this character, and in some cases special laboratories for this purpose have been installed which are quite distinct from the main research laboratories. This may be viewed as a very far-seeing business policy, directed to outstripping competition by the continuous provision of discoveries, which may sooner or later be turned to industrial account. It is recognized that in such cases there is a probability of a great deal of the new scientific knowledge thus obtained being only of limited use to the particular industry concerned. On the other hand, one successful discovery may result in such important industrial gains as to outweigh by far the cost of all the abortive research.

Researches of this type have carried a broader scientific spirit into the field of industrial investigations; and, while there is still much room for improvement in this direction, the signs of the times are encouraging. Important industrial research laboratories are taking a continually wider point of view with respect to the early publication of scientific data.

4. Research Applied to Public Service

Many industries and public utility companies find that the market for their products can be increased by a careful investigation of their customers' needs. Especially does this appear to be the case with electrical power supply companies, some of which maintain research laboratories for the investigation of new uses for electrical energy.

5. *Research for the Purpose of Establishing Standard Methods of Testing and Standard Specifications Connected with the Purchase of Raw Materials*

Large firms and associations carry out a considerable amount of investigation mainly with this object in view, and efforts of this kind are to a considerable extent rendered of common value through the channels afforded by the American Society for Testing Materials, of which the leading corporations are members. The Refractories Manufacturers Association, the United States Steel Corporation, the Barrett Company, the Gulf Refining Company, and the Barber Asphalt Paving Company are among those which are active in research of this nature.

An examination of the methods of industrial research must start with the admission that the most important discoveries have arisen from the work of men of science who have drawn their inspiration from the "supreme delight of extending the realm of law and order ever farther toward the unattainable goal of the infinitely great and the infinitely little." Wöhler, a pure investigator, by his classical experiments on the syntheetical production of urea, originated a new branch of science, organic chemistry, which has constituted the basis of the great industries connected with dyes, foods, drugs, petroleum, explosives and other commodities. An English chemist, Sir William Perkin, discovered in 1856 the first aniline dye, "mauvine," and thus laid the foundation of an enormous chemical industry. The late Sir William Ramsay remarked that it would have been impossible to predict, when Hofmann set Perkin as a young student at the Royal College of Chemistry to study the products of the base aniline, produced by him from coal-tar, that one dye factory alone would at a later date possess nearly 400 buildings and employ 350 chemists and 5,000 workmen. Other examples in the chemical field are the work of Schönbein, a Swiss schoolmaster, whose investigation into the action of nitric acid on paper and cotton resulted in the production of nitro-cellulose; and, in the physical field, Faraday's work on induced currents, upon which are based electric lighting and traction and the utilization of electricity as a motive power and for the transmission of energy.

The history of science shows, however, that the work of the "pure" scientist generally breaks off at a point before the industrial application of his discoveries is reached, either because he has no interest in or aptitude for this aspect of the work, or because the industrial application has to wait for some scien-

tific advance in another direction. The chemist who discovers a new organic compound may not consider himself under any obligation to investigate its utility in medicine; or the discoverer of a new rare earth may have no interest in its applicability in the manufacture of incandescent gas mantles. Some pause between scientific discovery and its industrial application is indeed almost inevitable, except in laboratories where the pure-research department hands over discoveries immediately to the industrial-development department. It is appropriate in this place to consider the history of aluminum, which was discovered by Wöhler in 1827. For some twenty years, the new element remained of academic interest only. In 1855, Henri Sainte Claire Deville's study of the metal, encouraged and subsidized by Emperor Napoleon III., reduced the cost of production to \$90 a pound; and, by improvements in the method of manufacture, the price was further reduced to \$12.50 a pound in 1888. In that year Castner's new process for the manufacture of sodium brought about a further reduction of the price of aluminum to \$4 a pound. But this success was soon eclipsed, for in the following year the electrolytic method of producing aluminum revolutionized the industry. The American consumption of aluminum produced by this method is estimated at over 100,000,000 pounds a year, whereas it amounted to but 283 pounds in 1885 and about 1,000,000 pounds in 1895. Another often-quoted example comes from the artificial production of indigo. The pure research of Liebig and Baeyer on the constitution of indigo was elucidated and developed through Kekulé's theoretical work in 1869 on the arrangement of the atoms in the molecule of indigo; and in 1880 Baeyer discovered a method for the industrial production of the dye. The problem was taken over by a famous firm of chemical manufacturers—the Badische Anilin-und-Soda-Fabrik, of Ludwigshafen. It is said that twenty years of patient investigation and an expenditure of about \$5,000,000 were devoted to the work. The artificial production of indigo is now carried out on a large scale, both here and abroad.

The scientific worker occasionally undertakes the commercial exploitation of his discoveries. The establishment of the celebrated Jena glass works at Leipzig resulted from the investigations of Abbe, assisted by Schott, on the chemico-physical principles which underlie the manufacture of optical glass. Abbe recognized from the first that the position of the optical glass industry, which depended at that time on a few individuals, was unsatisfactory, in view of the possible stoppage of sup-

plies indispensable to many of the sciences; but he doubted whether private initiative, without strong backing, could meet the case. The researches were, however, subsidized by the Prussian Bureau of Education and the Diet of the Kingdom; and, when completed in 1883, the necessary capital was forthcoming and an important industry was established. The attempt to establish a dye factory in England, at the time of Sir William Perkin's discoveries, ended disastrously. The real reason why the industry left that country, according to H. A. Roberts,² was the death of the prince consort, who had induced Hofmann to accept an appointment at the Royal College of Chemistry in London. After the death of the prince, Hofmann was attracted back to Berlin; his companions followed him, and took with them much of the expert knowledge of aniline dyes. W. F. Reid has controverted this opinion with respect to Hofmann's influence on the dye industry. He is authority for the statement that at that time English chemists controlled the dye manufacturing business by their patents, and made so much money out of it that they ceased to care whether the industry developed further or not; and that, when the matter dropped, the Germans took it up, and, by skill and patience, developed it to an enormous extent. The United States now has a firmly established dye industry, the result of activity during the past three years.

Enough has been said to indicate how important is the part which the academic worker has taken in the development of applied science. It should not be inferred, however, from the examples quoted, that valuable results are obtained only from scientific workers of the highest intellectual powers. Many examples could be given of discoveries by young and inexperienced men of factory processes of great commercial value, but comparatively simple in character.

THE LURE OF INDUSTRIAL RESEARCH

From all of our prominent institutions of learning, the combined lure of great research opportunities and of much larger financial returns has taken from academic life many of the promising young men on whom the country has been depending for the filling of university chairs as the older men now holding them gradually age and retire. Unless prompt measures are taken there will result in a few years such a dearth of first-class tried material for professorships that second-rate men will be placed where the national welfare needs the best, and

² Paper read before the Royal Society of Arts, February 28, 1912.

third- and fourth-rate men will be occupying positions wherein there should be young men of the highest promise in the period in which they are reaching full maturity. Indeed, it is greatly to be feared that even now we are witnessing a gradual lowering of standards in the science departments of our universities. It would be futile to appeal to the manufacturers not to call the men they need, although in the not distant future they will suffer most severely from the situation which is developing, if the present tendencies remain unchecked; for while our industries can provide for any urgently required research in pure science, it will never be safe for the nation to depend on the industrial laboratories for its progress in science, and men gifted with the genius for investigation must also be trained in and secured from the universities. The only possible source of relief lies with the presidents and trustees of our great universities.³ The authorities should recognize the fact that their institutions have now entered a period of severe competition between the industries and academic life for research chemists and engineers of the highest type and greatest promise. They have already learned the only method of meeting this competition successfully, for they have faced the same problem in two other professions, medicine and law: because of the tremendous financial attractions of the practise of these professions, the most progressive universities have simply put their law and their medical faculties on a higher, more nearly professional scale of endowment of professorships than obtains for their other faculties. They must take the same measures with their science staffs; it is primarily a question whether they can be awakened to that need now or whether they will let the country suffer from their lack of foresight and let us learn from the most efficient of our teachers, bitter experience. Wise provision now would not only safeguard our present standing in a critical period of our history, but in this time, when the importance of science and especially of chemistry has been brought home to our young men as never before, the new attitude, properly announced, would attract a large proportion of the men of brains, talent and ambition, who enter professional life, but prefer to study law or medicine as holding out much greater opportunities for the satisfying of their ambitions.

The manufacturing world will, however, always attract from our universities able investigators of pronounced energy who are anxious to do things on a large scale. On the other hand, those who are profoundly interested philosophically in the

³ See Stieglitz, *J. Am. Chem. Soc.*, 39 (1917), 2095.

nature of things will plan and conduct their researches without *special* thought of pecuniary or practical outcome and without serious regard for exigency, and from such investigations must come primarily any great discoveries of new principles which still remain to be made—and many such are still in the future. Researches of this type will always allure men of thought as contra-distinguished from men of action; and the real home of these investigators is the university because the time factor is there of secondary consideration. The volume, range and quality of industrial research are certain to continue to increase largely in the immediate future and the relative amount of time spent on pure research may decrease. It is not thought, however, that there will ever be any diminution in its absolute amount, and the leading advocates of industrial research are the first to urge the encouragement of pure research. Any general curtailment of research in pure science would be a most serious calamity. Scientific laws can not be reasonably applied until they are understood; therefore, research in pure science, which establishes the underlying foundation of the applied sciences, essentially precedes any efficient application of these laws. Hence, at least chronologically, the fertile investigator in pure science must also come first.